SUMMARY

BIOLOGY

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Chapter 6 : Energy and life

Concept 6.2 :The free-energy change of a reaction tells us whether or not the reaction occurs spontaneously.

- Biologists want to know which reactions occur spontaneously and which require input of energy.
- To do so, they need to determine energy changes that occur in chemical reactions.
- **free energy** (ΔG) is the energy that can do work when temperature and pressure are uniform, as in a living cell.

$$\Delta G = \Delta H - T\Delta S$$

ΔG= G (final state) - **G** (initial state)
ΔH : the change in the system's enthalpy (totat heat content)
ΔS: the change in the system's entropy (it is a measure of disorder)
K : temperature in Kelvin (k=C+273)

- Only processes with a negative ΔG are spontaneous.

- for ΔGto be negative,the system must lose heat (ΔHis negative) and become more disordered(TΔS is positive)

- Free energy is a measure of a system's instability, its tendency to change to a more stable state.
- During a spontaneous change, free energy decreases and the stability of a system increases.
- Equilibrium:

-is a state of maximum stability
-forwarder and backward reactions occur in the same rate
- G is at it's lowest possible value in that system.
- as a reaction proceeds toward equilibrium, G decreases.

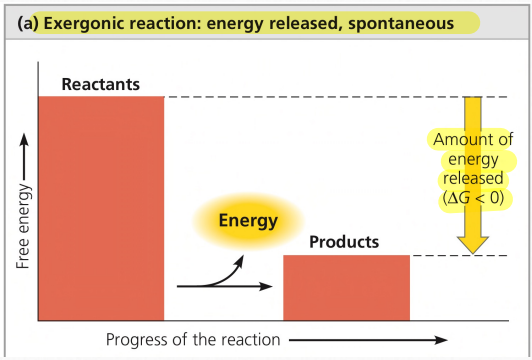
Exergonic and Endergonic Reactions in Metabolism

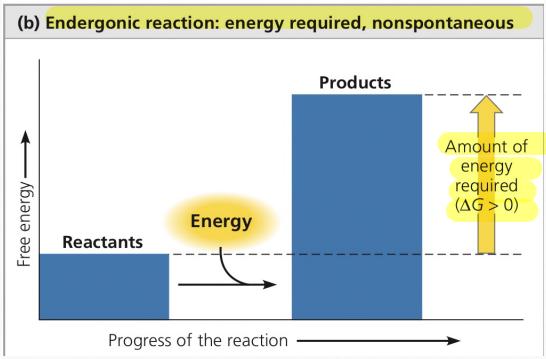
- An **exergonic reaction** proceeds with a net release of free energy (ΔG is negative)

-spontaneous reaction.

- An **endergonic reaction** absorbs free energy from its surroundings (ΔG is positive)

-nonspontaneous reaction





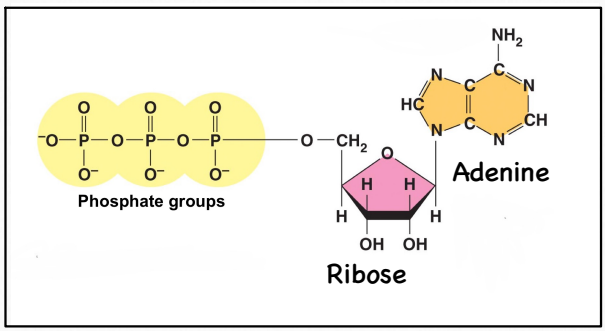
Equilibrium and Metabolism

- Reactions in a closed system eventually reach equilibrium and then do no work.
- Cells are not in equilibrium; they are open systems experiencing a constant flow of materials.
- A defining feature of life is that metabolism is never at equilibrium.
- A catabolic pathway in a cell releases free energy in a series of reactions.
- The three main work of cells:

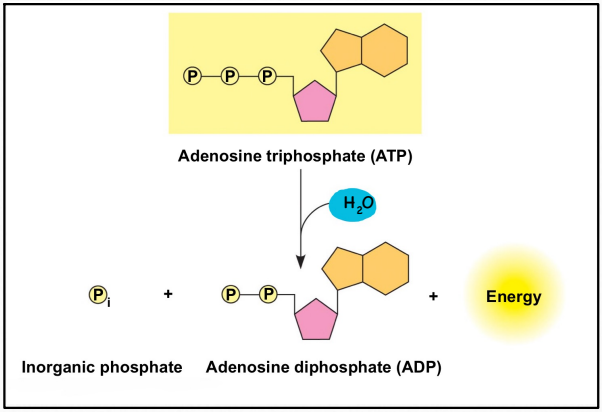
1. Chemical: (synthesis of polymers from monomers).
2. Transport: (the pumping of substances across membranes against the direction of spontaneous movement.
3. Mechanical:(contraction of muscle cells)

ATP

- ATP (adenosine triphosphate) is an organic compound that provides energy to drive many processes in living cells .
- ATP is composed of ribose (a sugar), adenine (a nitrogenous base), and three phosphate groups.

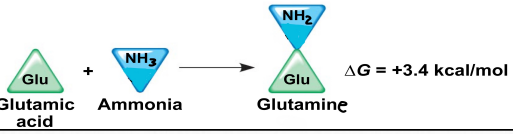


- The bonds between the phosphate groups of ATP's tail can be broken by hydrolysis.
- Energy is released from ATP when the terminal phosphate bond is broken.
- This release of energy comes from the chemical change to a state of lower free energy, not from the phosphate bonds themselves.
- the products of ATP hydrolysis are more stable and have lower free energy.



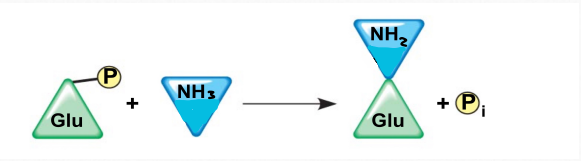
- To do work, cells manage energy resources by energy coupling, the use of an exergonic process to drive an endergonic one.
- In the cell, the energy from the exergonic reaction of ATP hydrolysis can be used to drive an endergonic reaction.
- Overall, the coupled reactions are exergonic.

Endergonic reaction



Coupled with ATP hydrolysis, an exergonic reaction

1- ATP phosphorylates glutamic acid, making it less stable



2- Ammonia displaces the phosphate group, forming glutamine.

$Glu + NH_3 \longrightarrow Glu—NH_2$ $\Delta G = +3.4$ kcal/mol

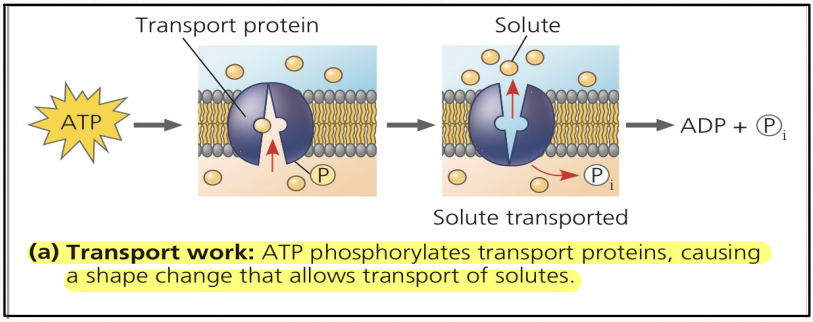
$ATP \longrightarrow ADP + P_i$ $\Delta G = -7.3$ kcal/mol

Net $\Delta G = -3.9$ kcal/mol

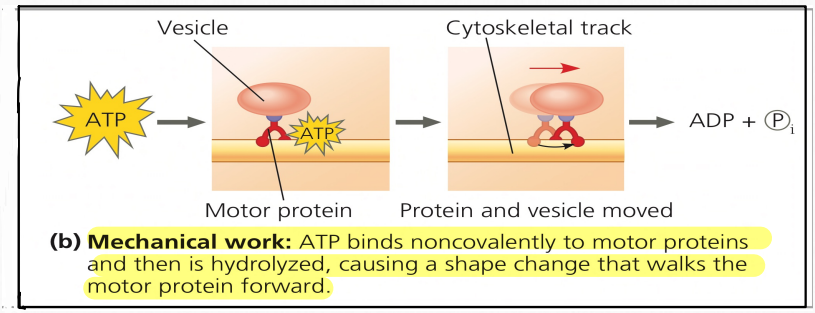
(c) Overall free-energy change

- ATP drives endergonic reactions by phosphorylation, transferring a phosphate group to some other molecule, such as a reactant.
- The recipient molecule is now phosphorylated.

- **ATP drives transport process and mechanical work inside the cell.**



(a) Transport work: ATP phosphorylates transport proteins, causing a shape change that allows transport of solutes.

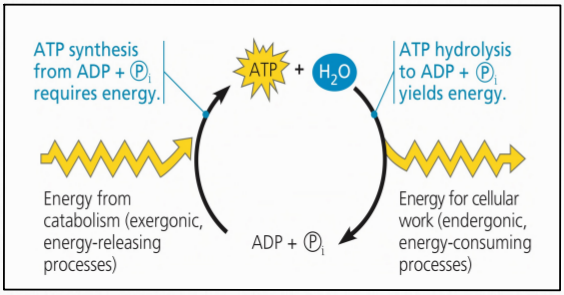


(b) Mechanical work: ATP binds noncovalently to motor proteins and then is hydrolyzed, causing a shape change that walks the motor protein forward.

The Regeneration of ATP

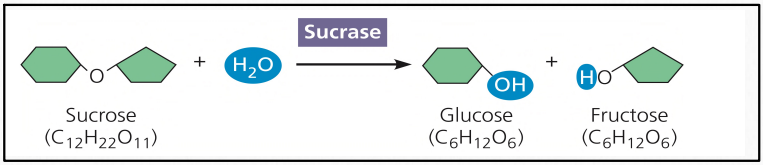
- ATP is a renewable resource that is regenerated by addition of a phosphate group to adenosine diphosphate (ADP).
- The energy to phosphorylate ADP comes from catabolic reactions(breaking macromolecules to get energy) in the cell.
- the regeneration of ATP is necessarily endergonic reaction (non-spontaneous)
- • ADP +P ⟶ ATP + H2O

ΔG = +7.3 kcal/mol (+30.5 kJ/mol)



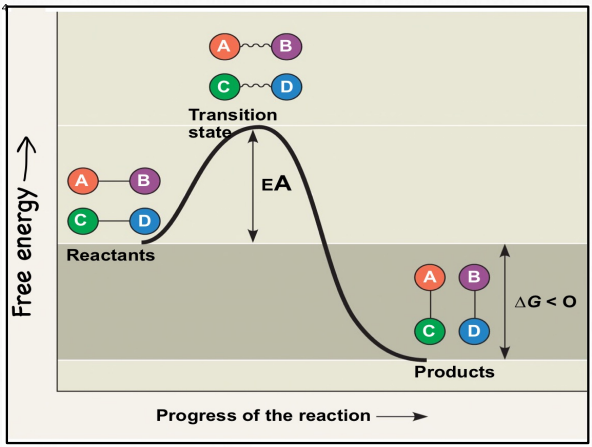
Enzymes speed up metabolic reactions by lowering energy barriers

- A spontaneous chemical reaction without any requirement for outside energy , but it may occur so slowly.
- A catalyst is a chemical agent that speeds up a reaction without being consumed by the reaction.
- An enzyme is a catalytic protein.
- Hydrolysis of sucrose by the enzyme sucrase is an example of an enzyme-catalyzed reaction.



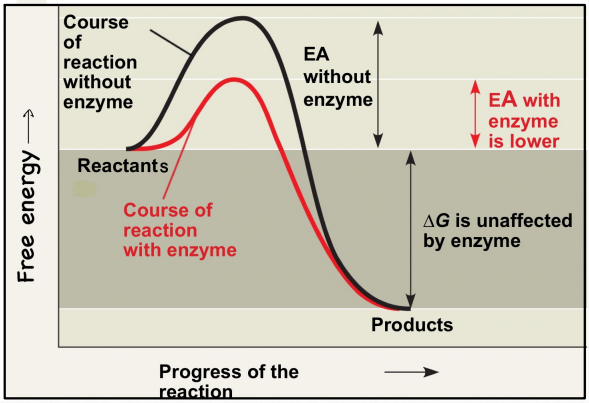
The Activation Energy Barrier

- Every chemical reaction between molecules involves bond breaking and bond forming.
- The initial energy needed to start a chemical reaction is called the **free energy of activation, or activation energy (EA)**
- Activation energy is often supplied in the form of heat from the surroundings.



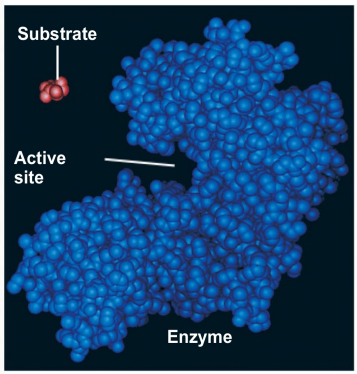
» How Enzymes speed up reactions ?

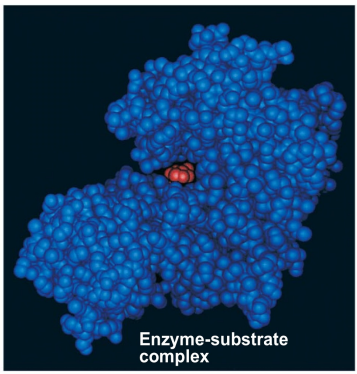
- Enzymes catalyze reactions by lowering the EA barrier
- Enzymes do not affect the change in free energy (ΔG); instead, they speed up reactions that would occur eventually.



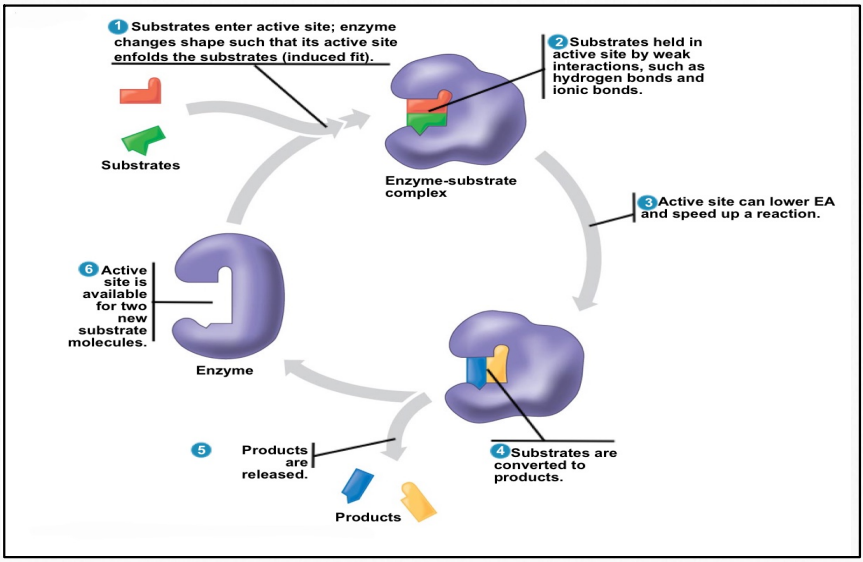
Substrate Specificity of Enzymes

- The reactant that an enzyme acts on is called the enzyme's **substrate**
- The enzyme binds to its substrate, forming an **enzyme-substrate complex**
- The **active site** is the region on the enzyme where the substrate binds.
- As the substrate enters the active site, the enzyme changes shape slightly.
- This shape change makes the active site fit even more closely around the substrate -this is called **induced fit** .
- **Induced fit** of a substrate brings chemical groups of the active site into positions that enhance their ability to catalyze the reaction





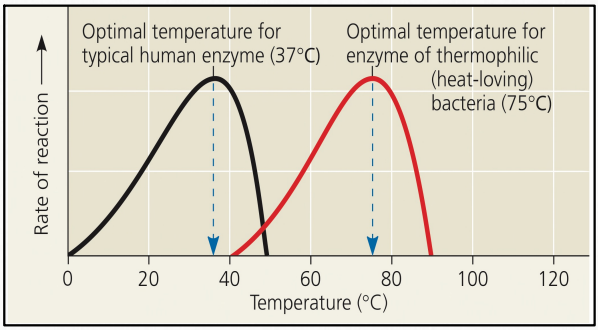
• In an enzymatic reaction, the substrate binds to the active site of the enzyme.
• The active site can lower an EA barrier by:
-Orienting substrates correctly
-Straining substrate bonds (helping it approach the transition state and reduces the amount of free energy that must be absorbed to achieve that state)
-Providing a favorable microenvironment (Ex : low pH environment in a neutral cell)
-Covalently bonding to the substrate

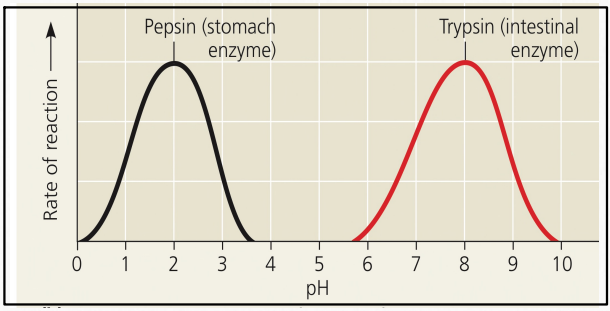


• The rate at which a particular amount of enzyme converts substrates to products depends on the initial concentration of the substrate: The more substrate molecules that are available, the more frequently they access the active sites of the enzyme molecules.
• However, there is a limit to how fast the reaction can be pushed by adding more substrate to a fixed concentration of enzyme. At some point, the concentration of substrate will be high enough that all enzyme molecules will have their active sites engaged ,at this substrate concentration the enzyme is said to be saturated,and the rate of the reaction is determined by the speed at which the active site converts substrate to product .
• when an enzyme population is saturated, the only way to increase the rate of product formation is to add more enzymes.

Effects of Local Conditions on Enzyme Activity

- the three dimensional structures of enzymes are sensitive to their environment.
- The rate of enzyme activity increases with increasing temperature, as the speed of the molecules increases and thus the chance of colliding with the active site of the enzyme increases.
- Optimal temperature:
- human enzymes: 35-40 ℃
- thermophile bacteria: 70 ℃ or higher
- the optimal pH values for most enzymes: 6-8
- pepsine : a digestive enzyme in the stomach , has an optimal pH of 2
- trypsin : a digestive enzyme in human intestine , has an optimal pH of 8





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Cofactors: non-protein helpers for catalytic activity.

- types of cofactors:
- inorganic: metal atoms, zinc, iron, and cooper in ionic form.
- organic :they are called coenzymes such as vitamins.

Enzyme inhibitors

• Enzyme inhibitors are Certain chemicals selectively inhibit the action of specific enzymes.

1- irreversible inhibitor: attaches to the enzyme by covalent bonds

Ex: toxins and poisons are often irreversible inhibitors

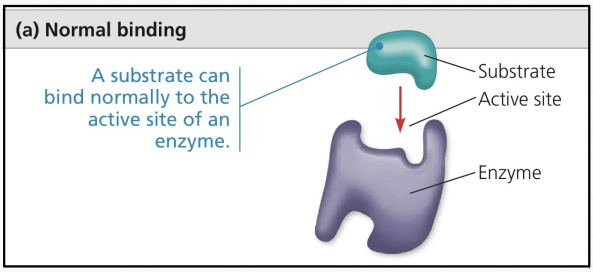
2- reversible: bind to the enzyme by weak interactions

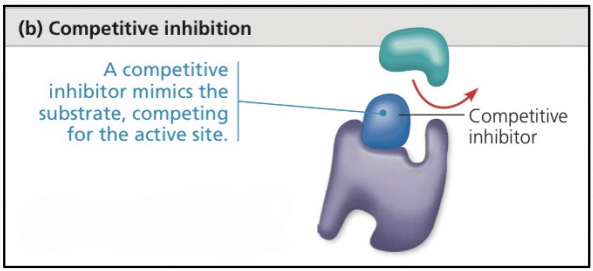
• there are two typpes of inhibitors:

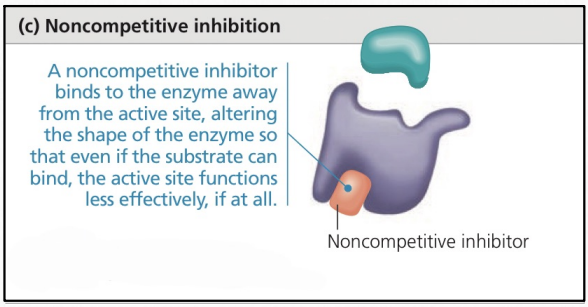
1- competitive inhibitors: reduce the productivity of enzymes as they compete with substrates by binding to the active site and subsequently block substrates from entering the active site.

-this competition can be overcome by increasing the concentration of substrate.

2- Noncompetitive inhibitors: This inhibitor binds to a different site than the active site causes the enzyme to change its shape in such a way that the active site becomes less effective at catalyzing the conversation of substrate to product.





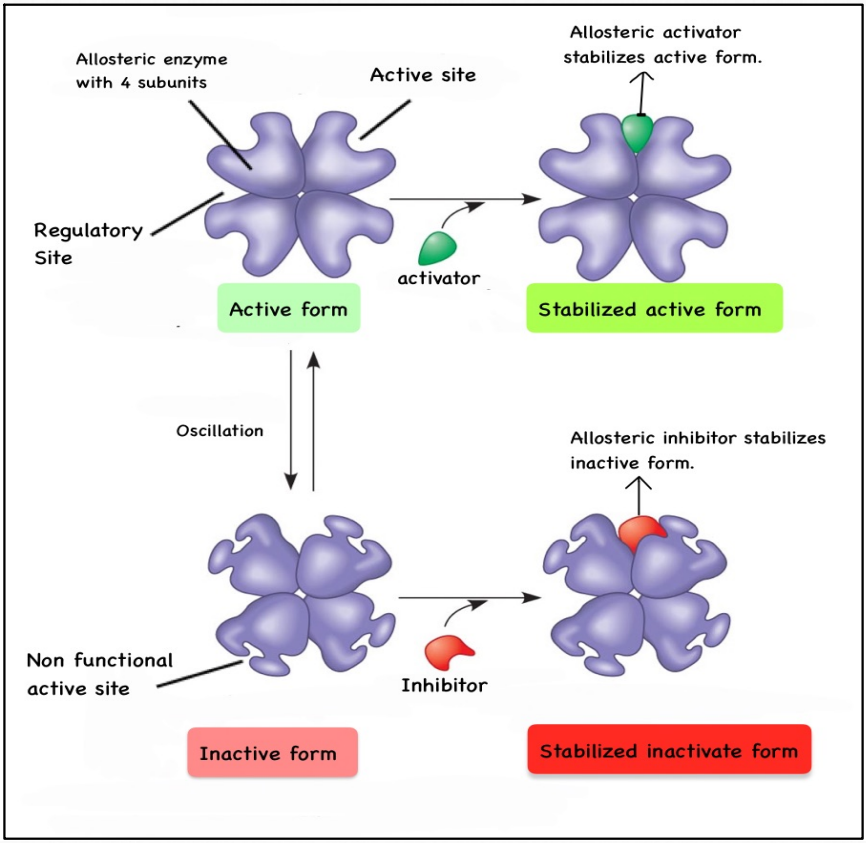


💥Allosteric Regulation of Enzymes

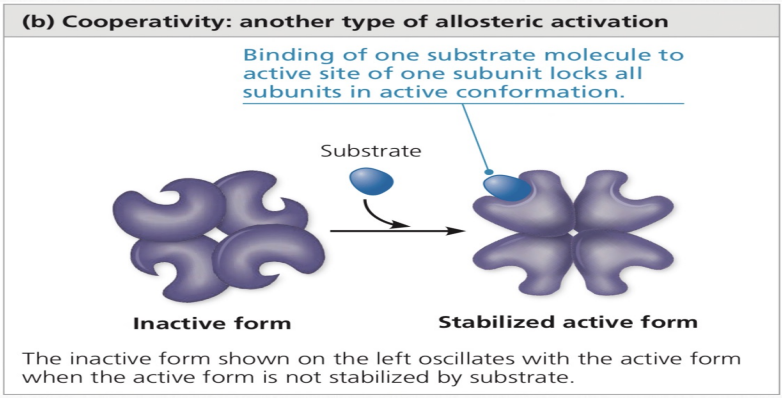
- Allosteric regulation may either inhibit or stimulate an enzyme's activity.
- Allosteric regulation occurs when a regulatory molecule binds to the enzyme at one site and affects the enzyme's function at another site (the active site)
- Most allosterically regulated enzymes are made from two or more subunits.
- Each enzyme has active and inactive forms.

-The binding of an activator stabilizes the active form of the enzyme.

-The binding of an inhibitor stabilizes the inactive form of the enzyme.

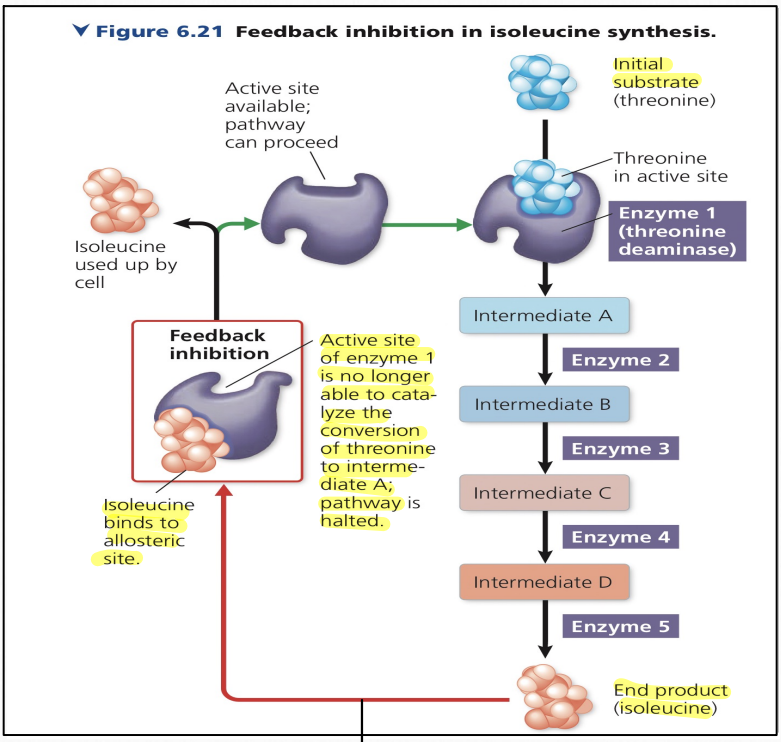


- **Cooperativity** is a form of allosteric regulation that can amplify enzyme activity.
- In cooperativity, binding by a substrate to one active site stablizes the active conformation at all other subunits.



Feedback Inhibition

- In feedback inhibition, the end product of a metabolic pathway shuts down the pathway.
- Feedback inhibition prevents a cell from wasting chemical resources by synthesizing more product than is needed.



as isoleucine accumulates , it prevents it's own Synthesis by inhibiting the enzyme for the first step of the pathway